Radiation Damage and Radiation Resistant Magnets

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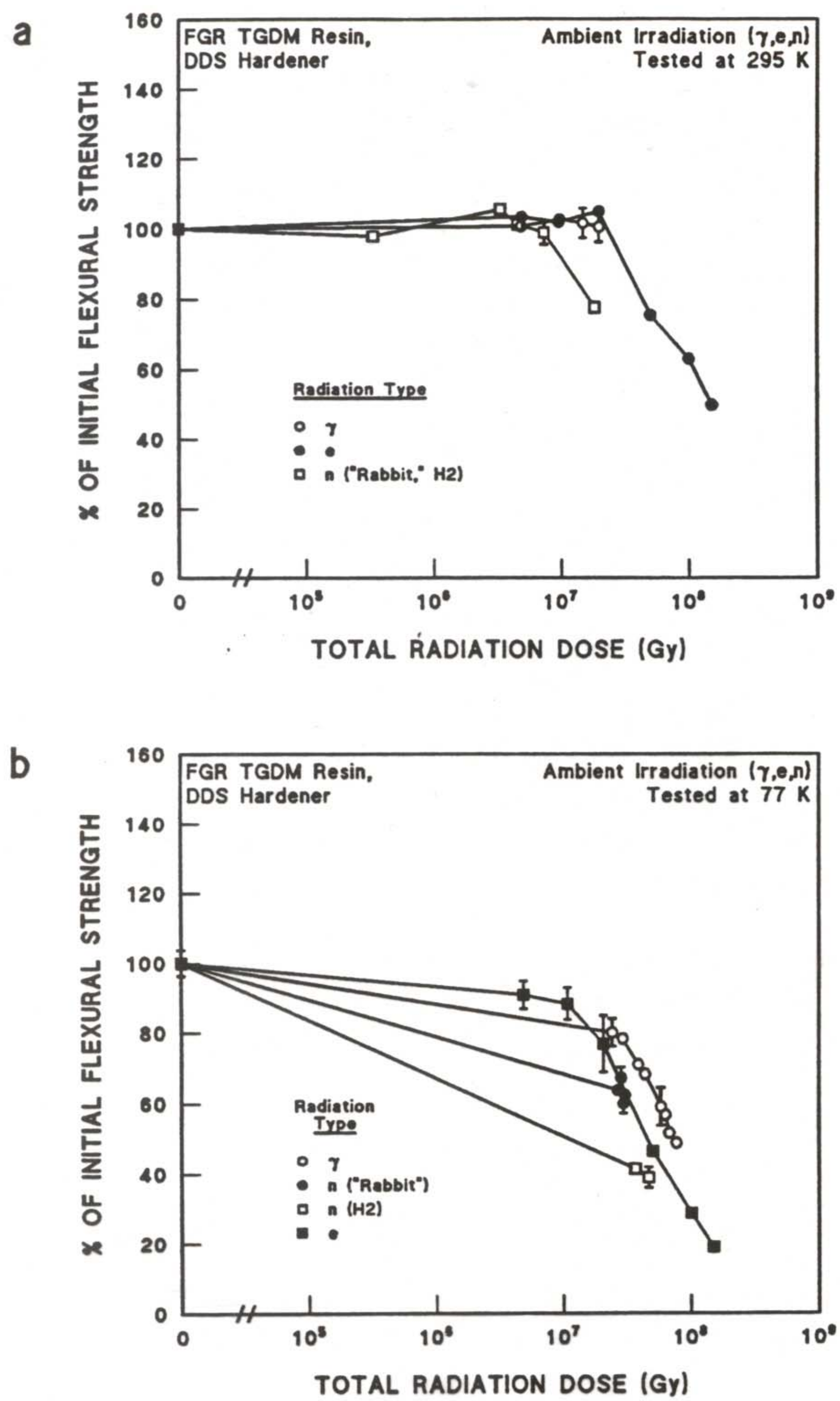


Figure 1.20. Irradiation data comparing the effects of neutron, electron, and gamma irradiation on a fiber-glass reinforced TGDM (tetraglycidyl diaminodiphenyl methane) epoxy matrix cured with DDS (diaminodiphenyl sulphone). (a) Flexural tests at 295 K. Data from Egusa et al. [1984a, b]. (b) Flexural tests at 77 K. Data from Egusa et al. [1985a; 1987b]. The H2 irradiation thimble exposed specimens to a heavier dose of thermal neutrons than the "Rabbit" thimble. (Supplementary Table B.1-1.)

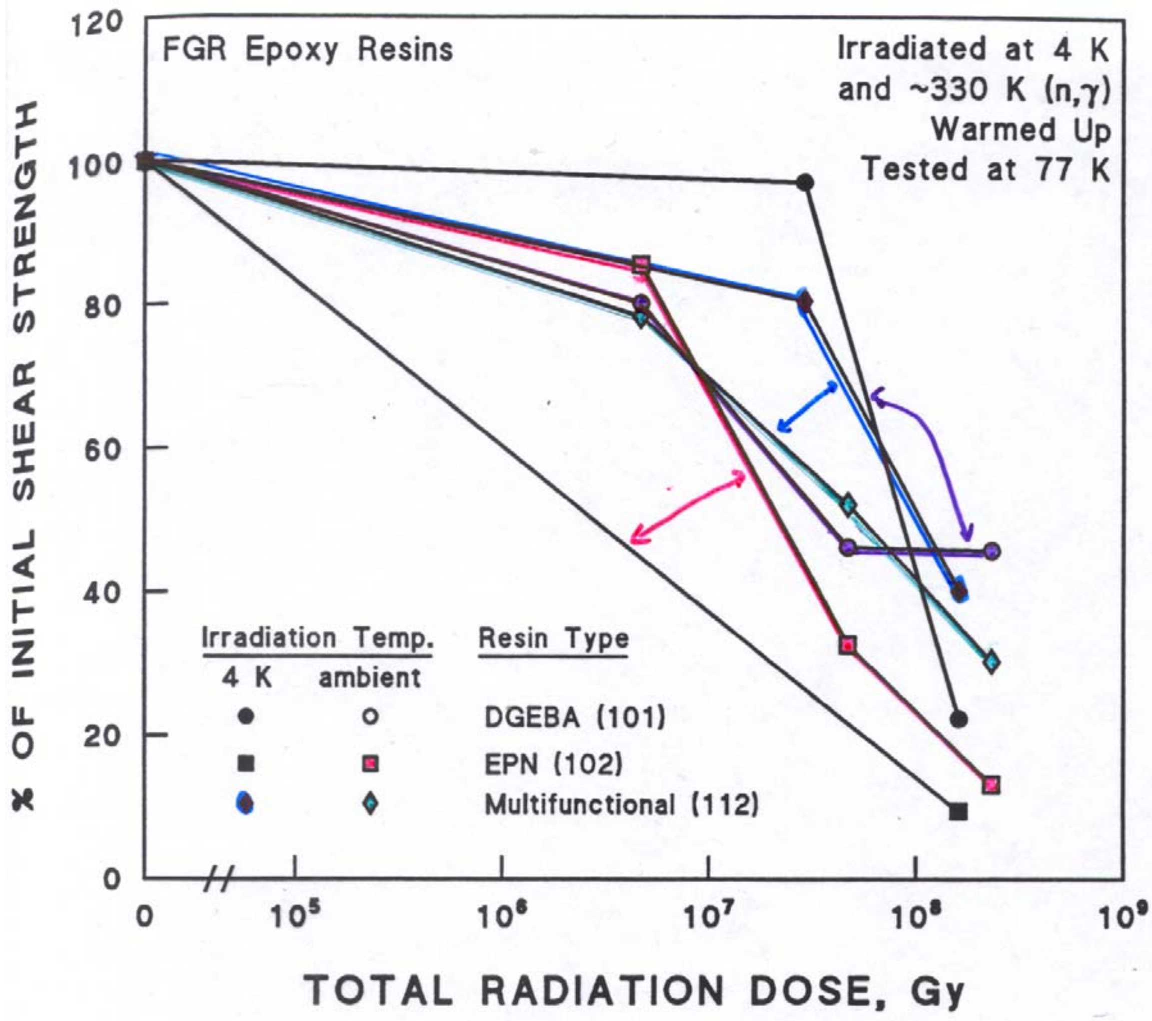


Figure 1.25. A comparison of the shear strengths of three types of reinforced epoxy resins that were reactor-irradiated at both 4 K and at ambient temperature. See text for differences in the fast neutron spectrum in the two reactors. Data from Munshi [1991]. (Supplementary Tables A. 3-3 and A. 8-4.)

General Radiation Limits for Several Materials

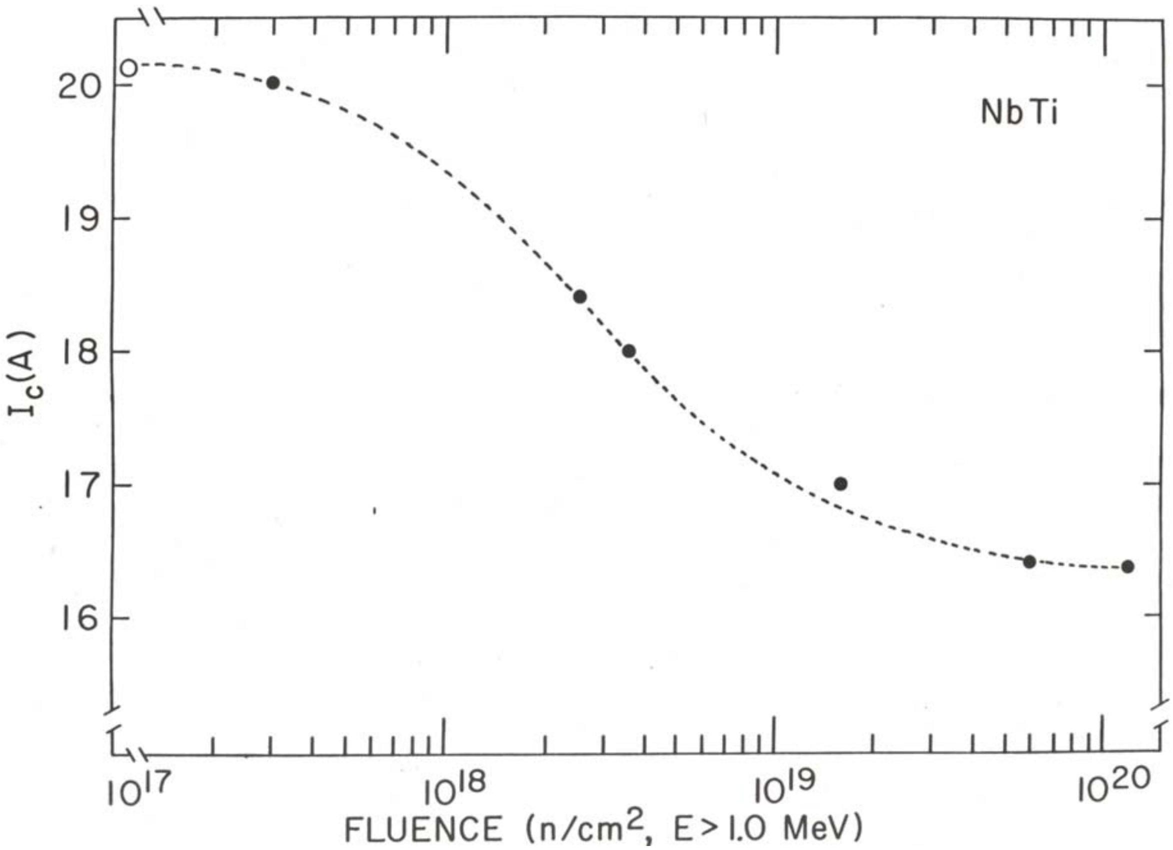
NbTi: ~ 10^{19} n/cm^2 E>.1 MeV
Nb_3Sn: A little bit better

Note: 10^{19} n/cm^2 = 10^8 Gy = 10^{10} Rad

Organics: 10^6 to 10^8 Gy

Ceramics: > 10^9 Gy

Copper: > 10^{10} Gy


NbTi
20
19
18
17
16
$I_c(A)$
10^{17}
10^{18}
10^{19}
10^{20}
FLUENCE (n/cm^2, E > 1.0 MeV)

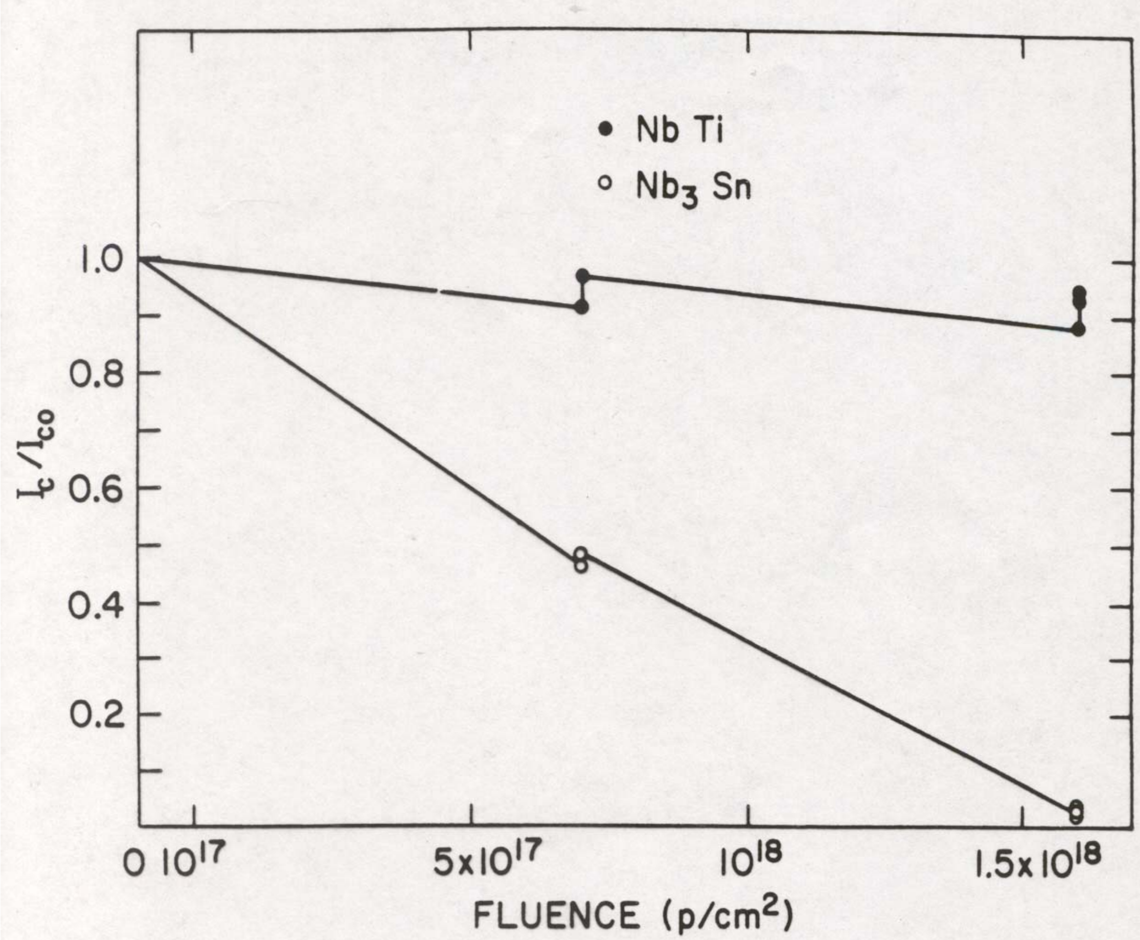


Fig. 13. A comparison between the critical-current degradation of NbTi and Nb_3Sn for identical 30-GeV-proton irradiations and anneals. The critical currents were determined at 4 T. Anneal are for 273 K for the low-fluence point, and for 77 and 273 K for the high-fluence data. (After Snead 19778.)

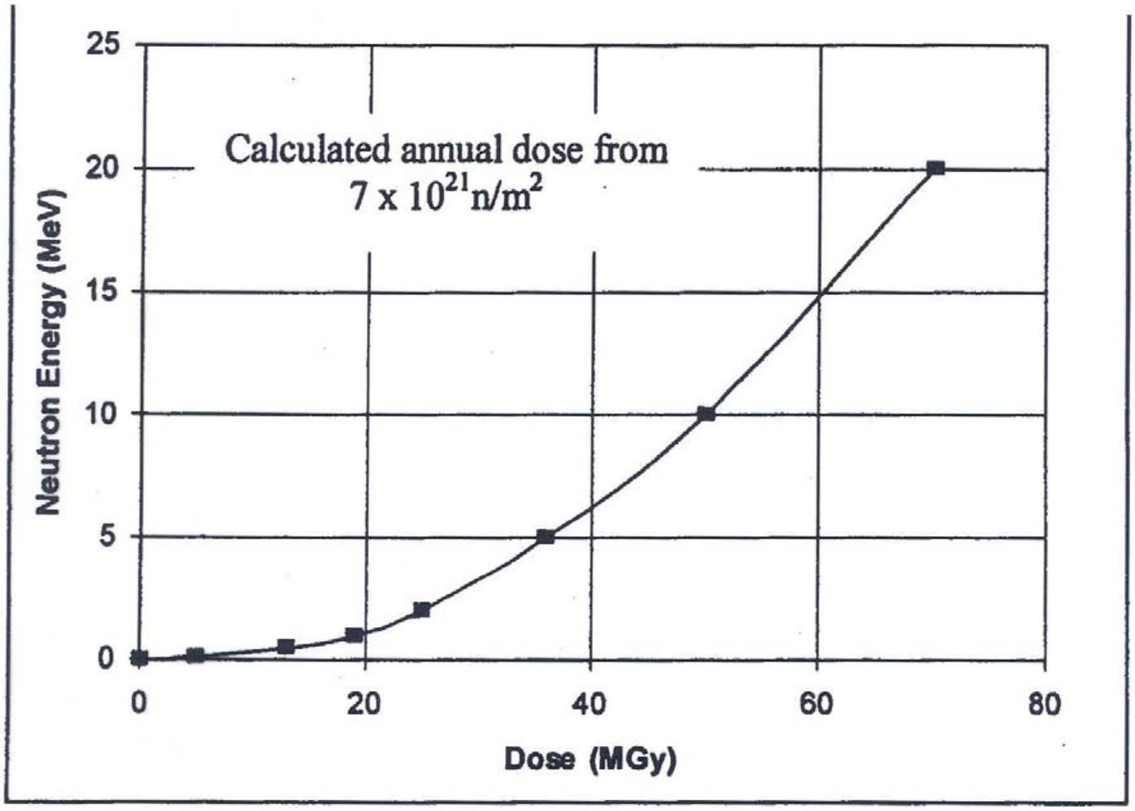
Vertical movement of the data point at 0.7 and 1.6 x 10^{18} p/cm². The three points at the higher fluence represent the samples irradiated, annealed 125 K, and then to 290 K. The lack of recovery in the Nb_3Sn specimen is the striking feature that contrasts sharply with the recovery behavior of NbTi. For neutron damage in Nb_3Sn induced above room temperature we have seen that critical-current degradations and T_c reductions start becoming significant at the ~ 2 x 10^8 n/cm² fluence level for neutrons (reactor spectrum, E > 1 MeV). This corresponds to a damage energy of ~ 0.2 eV/atom (see for instance, Parkin and Snead 1975, 1981).

NbTi:

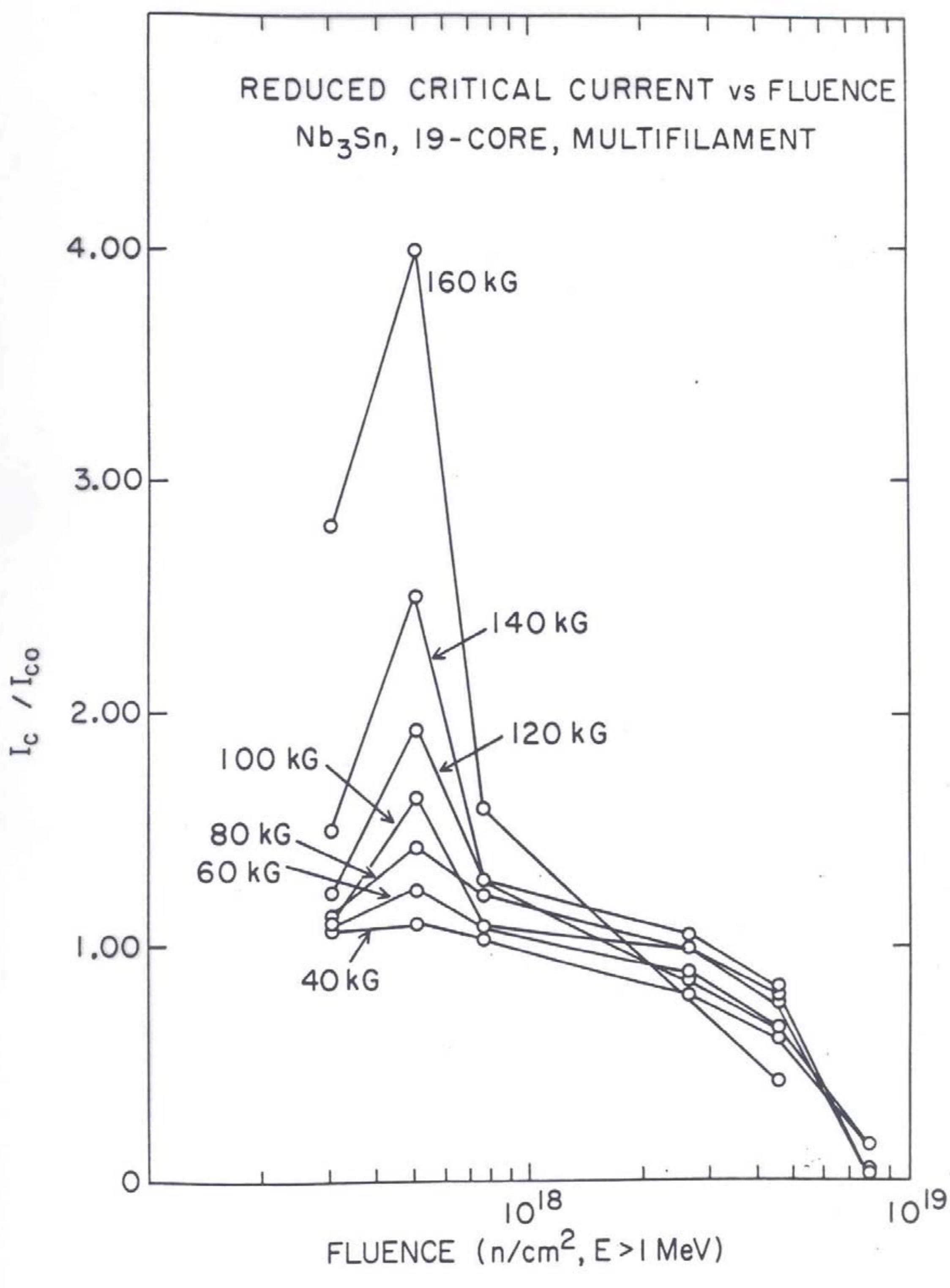
I_c reduced by ~ 20% for 2 X 10^{19} n/cm^2 for neutrons with E > .1 Mev

Loss remains at that level until at least 10^{22} n/cm^2

Needs work at higher energies and fluxes



From Reed and Evans



REDUCED CRITICAL CURRENT vs FLUENCE
Nb_3Sn, 19-CORE, MULTIFILAMENT
4.00
3.00
2.00
1.00
0
I_c / I_{co}
160 kG
140 kG
120 kG
100 kG
80 kG
60 kG
40 kG
10^{18}
10^{19}
FLUENCE (n/cm^2, E > 1 MeV)

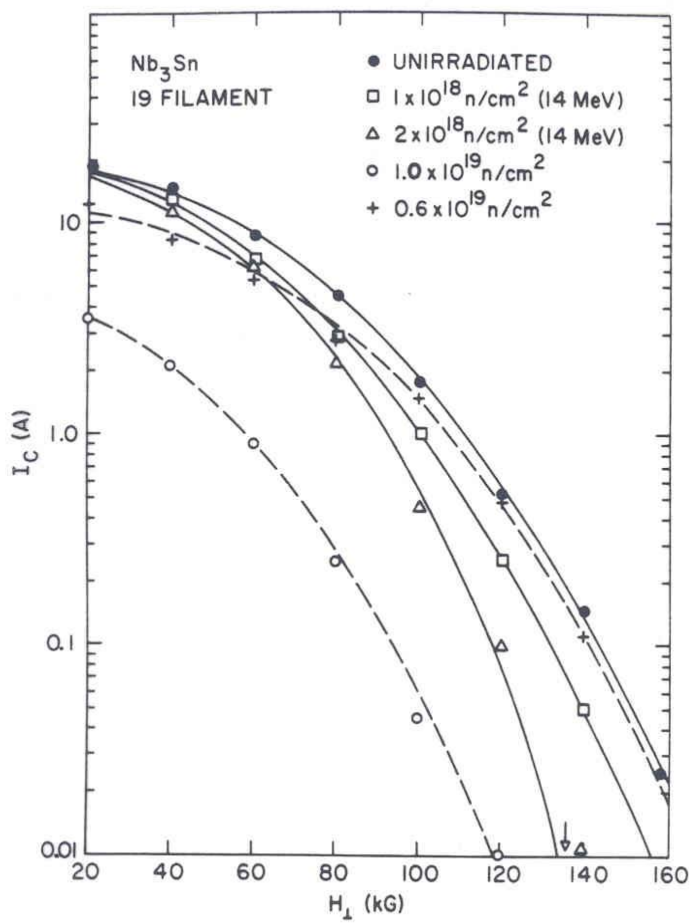
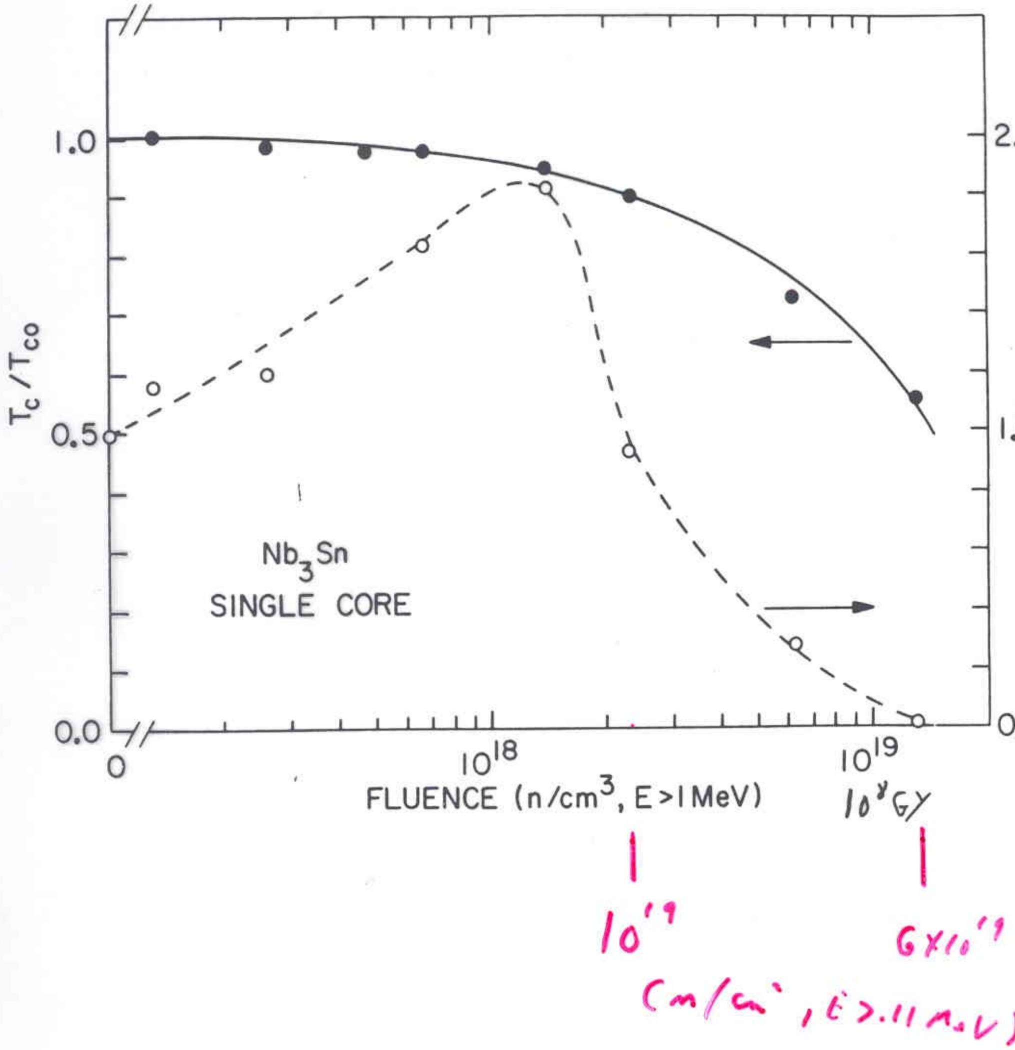


Fig. 16. The critical current is plotted versus applied field for two fluences of 14-MeV-neutron irradiations performed at room temperature. Also plotted for comparison are the results for two comparable fleeces of fission-reactor neutrons. (After Snead et al. 1976.)

This analysis (admitting that the peak, or Imax, had not been reached for the fluences of either irradiation), a conclusion that possibly two mechanisms were at work, presumably pinning at cascades and increasing H_{c2} due to increasing ρ_N. The lack of recovery in the high-energy-neutron case in annealing to room temperature, whereas the Brown et al. results did show recovery, argues that possibly the cascade effects are more important in the high-energy case than for the fission-reactor neutron case.


1.0
0.5
0.0
2.0
1.0
0.0
T_c / T_{co}
$I_c / I_{co}(10\,T)$
Nb_3Sn
SINGLE CORE
0
10^{18}
10^{19}
FLUENCE (n/cm^3, E > 1 MeV)
10^8 Gy
10^{19}
6×10^{19}
(n/cm^2, E > .1 MeV)

Superconductor limits:

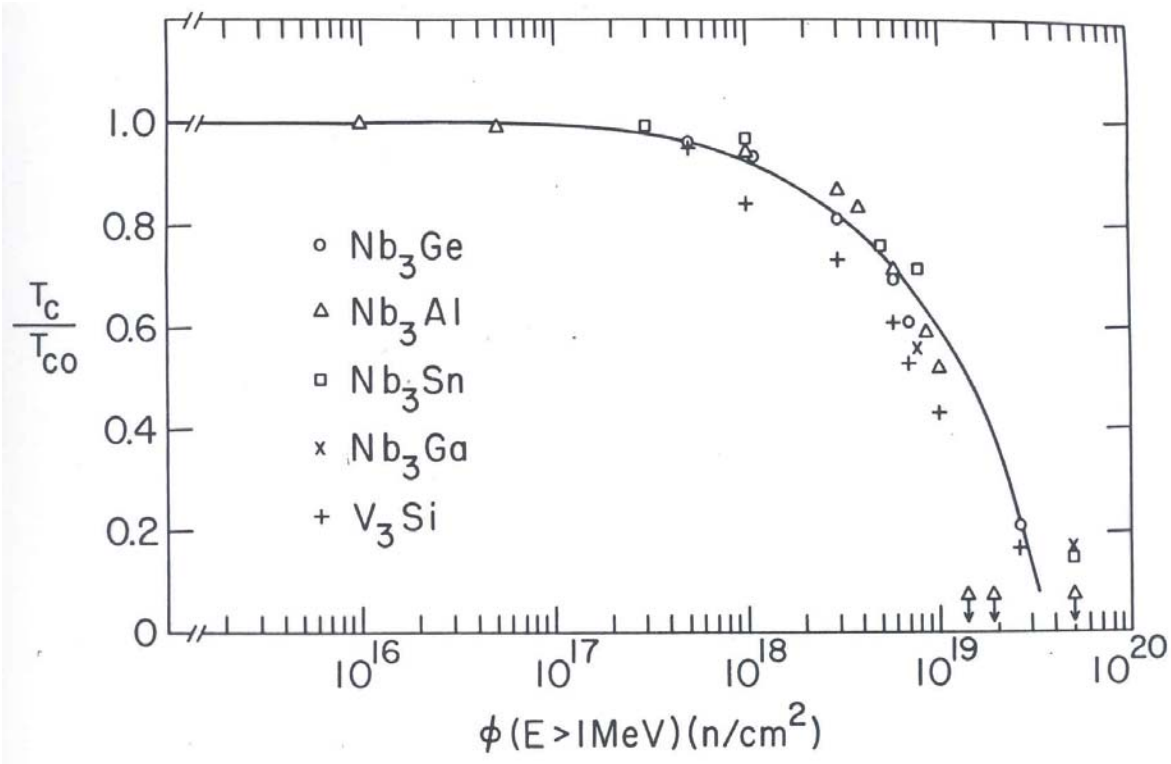
Nb_3Sn:

$I_c = 0$ for any of the following:
5×10^8 Gy absorbed dose

1×10^{20} n/cm^2 for neutrons with E > .1 Mev

8×10^{18} n/cm^2 for neutrons with E > 1 Mev

Unknown for neutrons with E > 14 MeV


1.0
0.8
0.6
0.4
0.2
0
$\frac{T_c}{T_{co}}$
o Nb_3Ge
Δ Nb_3Al
□ Nb_3Sn
x Nb_3Ga
+ V_3Si
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
ϕ(E > 1MeV)(n/cm^2)

From Sneed

Copper

The material itself good for at least 10^{11} Gy

Radiation causes increase in resistance - protection issue

C

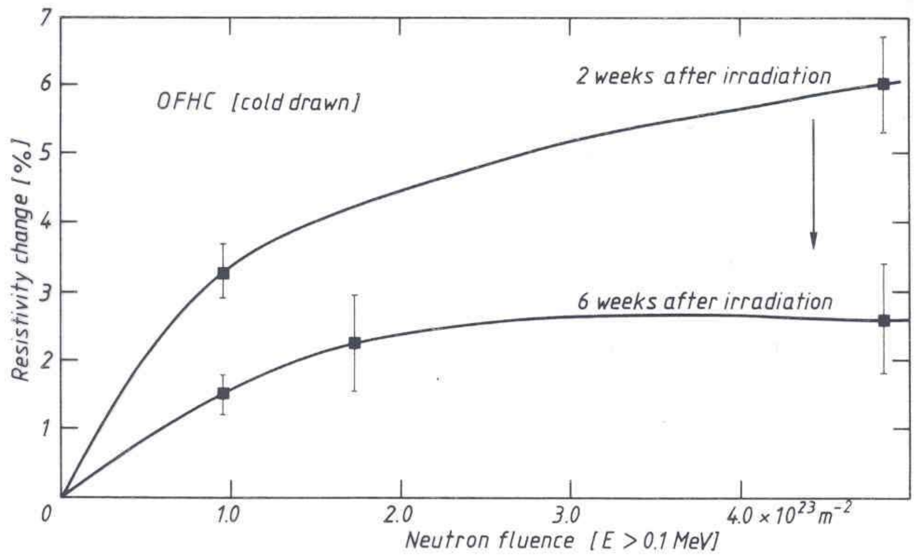
COPPER WIRE

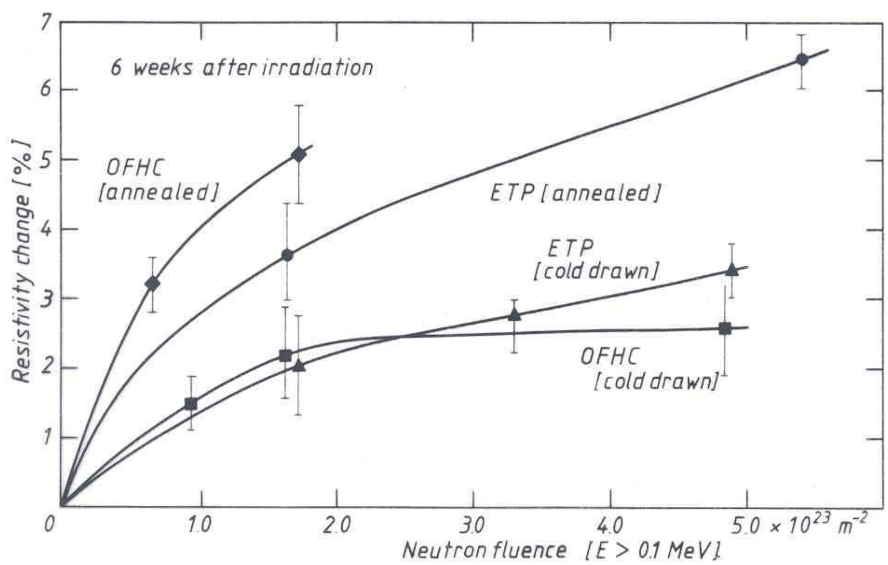
BASE MATERIAL: Copper

TYPE: OFHC and ETP

SUPPLIER: -

IDENTIFICATION: 239–1975





SYMBOL	PROPERTY	INITIAL VALUES	REMARKS
●	resistivity (I = 100 mA) at 22 °C	not measured	ETP annealed
■			OFHC cold drawn
▲			ETP cold drawn
◆			OFHC annealed

Radiation Resistances:

Inorganic insulation (e.g. Al2O3 or spinel)
> 1000 Mgy

Superconductor 500 MGy

Epoxy:

Use regular epoxy, enclose in container and let deteriorate powder trapped

Inorganic epoxy?
Differential contraction problems

CICC coils get their strength from the cable, so major requirement is dielectric strength

Inorganic insulators such as Al_2O_3 and $MgAl_2O_4$ (spinel) have excellent radiation resistance ($>10^{11}$ Gy)

Electrical insulation:

External anodization

Good insulation

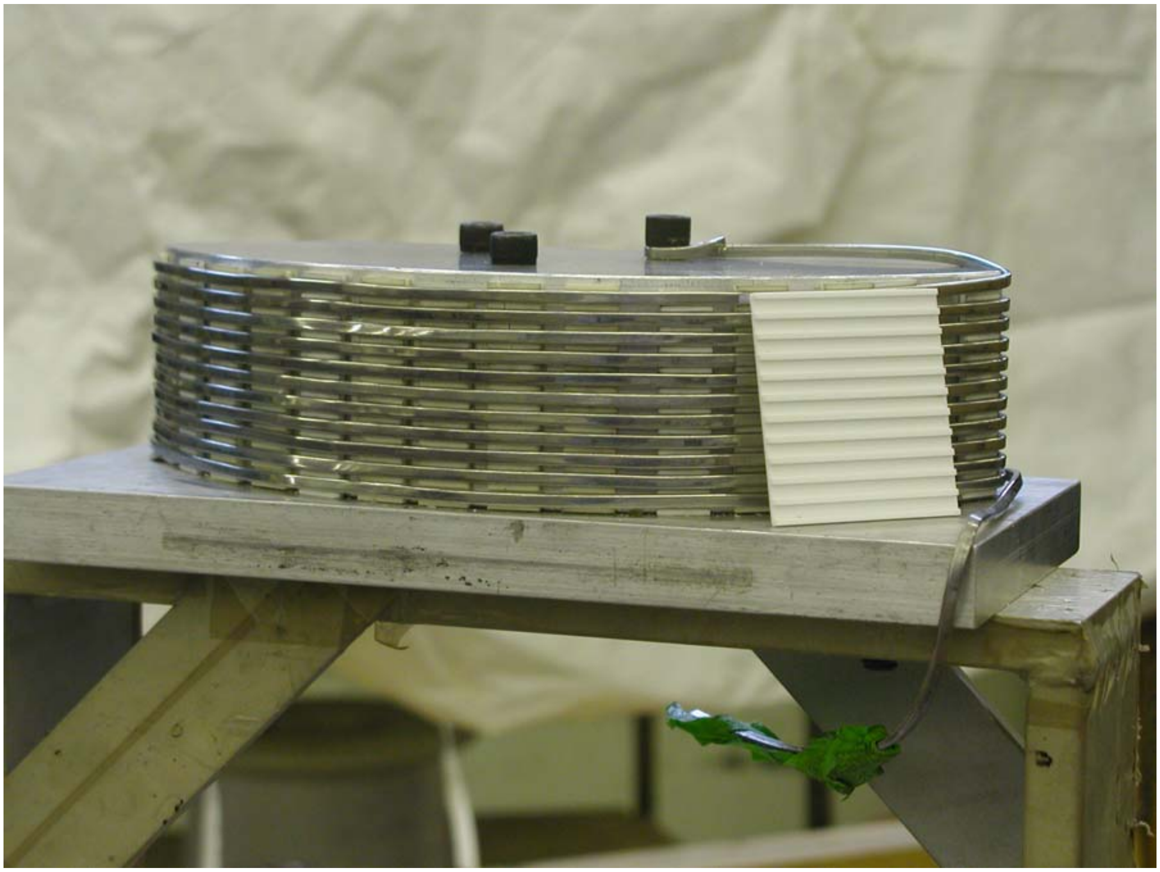
How do you clamp?

Other inorganic materials (MgO_2, spinel)

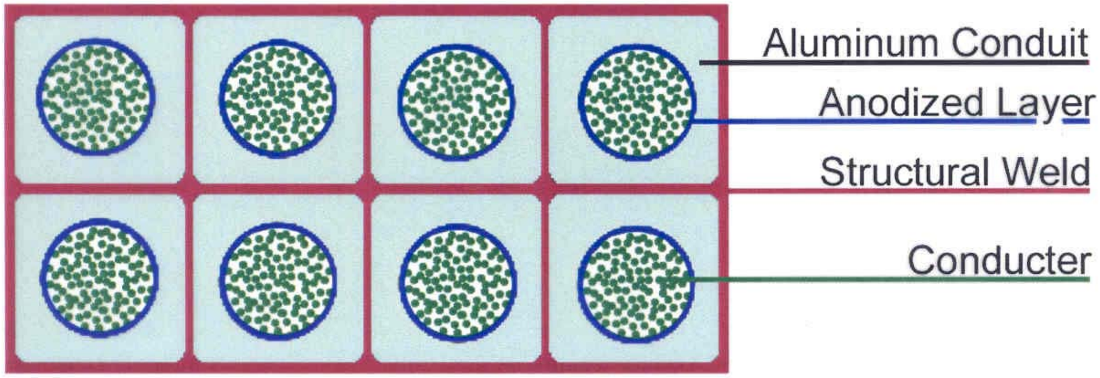
plasma spray for example

somewhat porous

How to clamp?



Cryostable test coil using alumina spacers



Schematic of an internally anodized CICC coil.

Anodic layer exaggerated for clarity.

Aluminum OK for NbTi

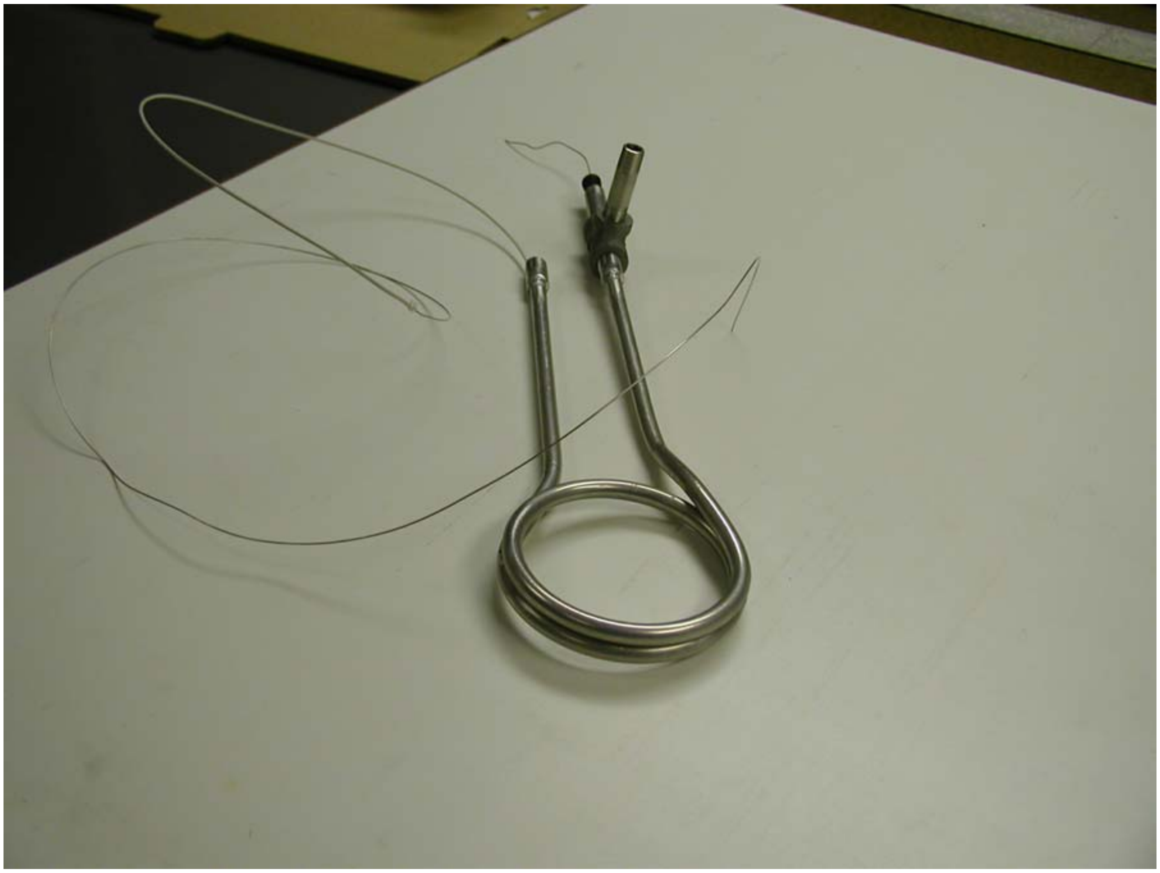
Nb_3Sn ?

Wind-and-react temperature ~ 700 C
aluminum mp = 660 C

need higher mp material:
Ti
Ti alloys used for cryogenic work:
Ti-2Al-4V and Ti-5Al-2.5Sn

Ti anodic layer good for at least 100 VDC

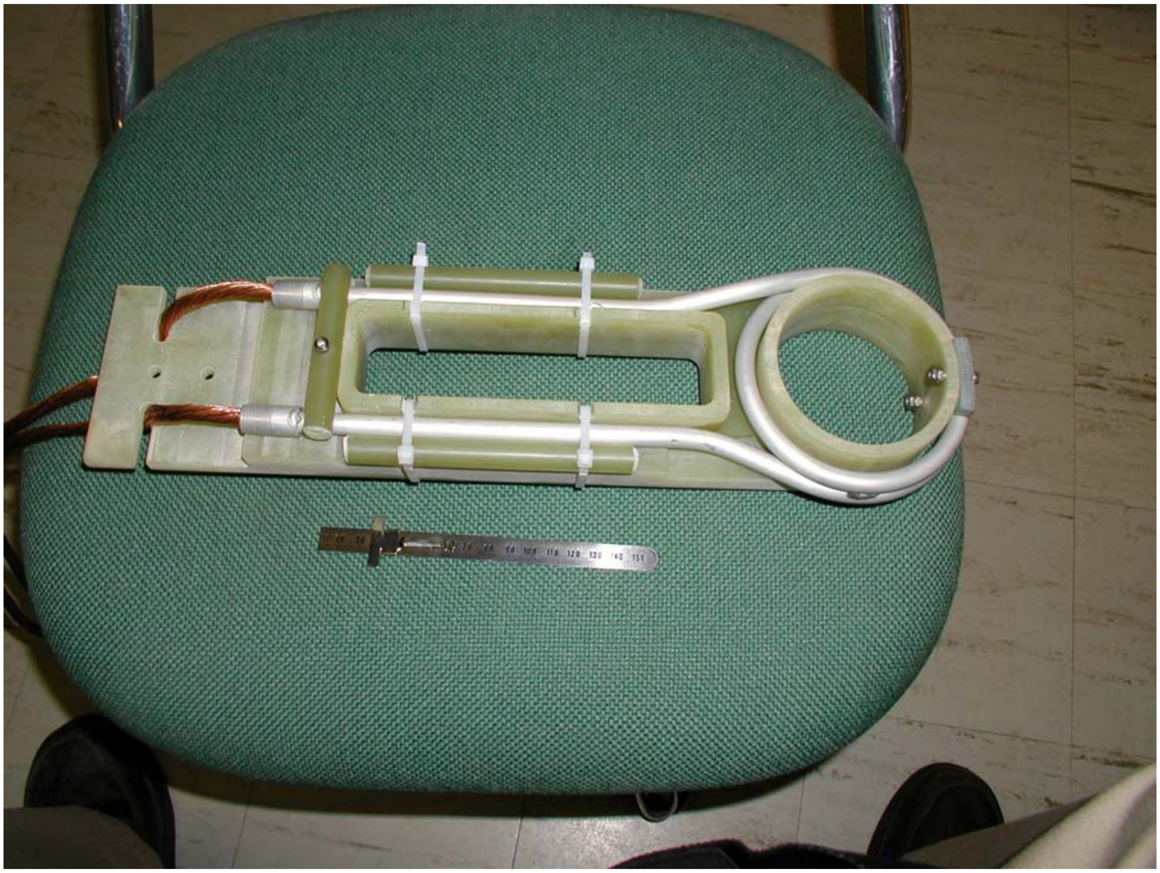
anodic layer thin and not very tough
(needs anodic development)



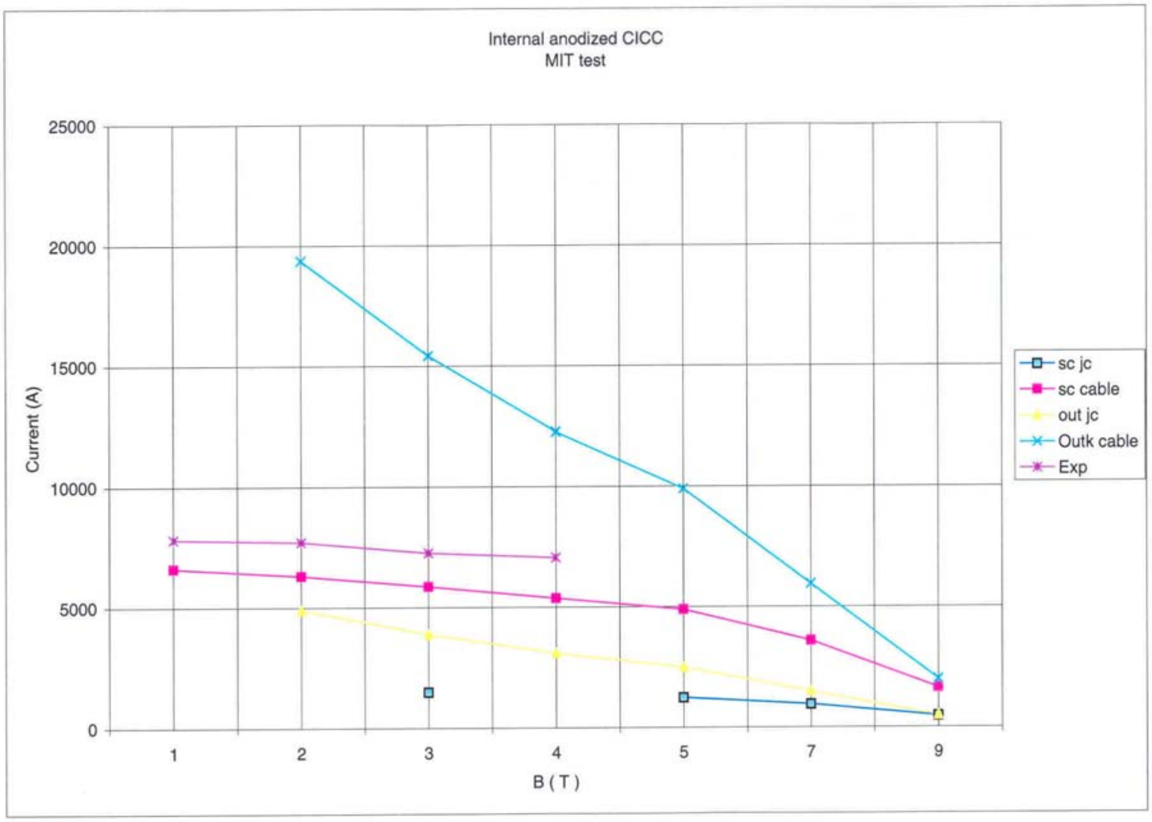
Anodizing set up for test coil

Polyvinyl alcohol wrap around cable to ease insertion. It is removed by passing hot water thru the pipe.

Cable after removal of polyvinyl alcohol



Test coil in fixture for testing at MIT



Test results

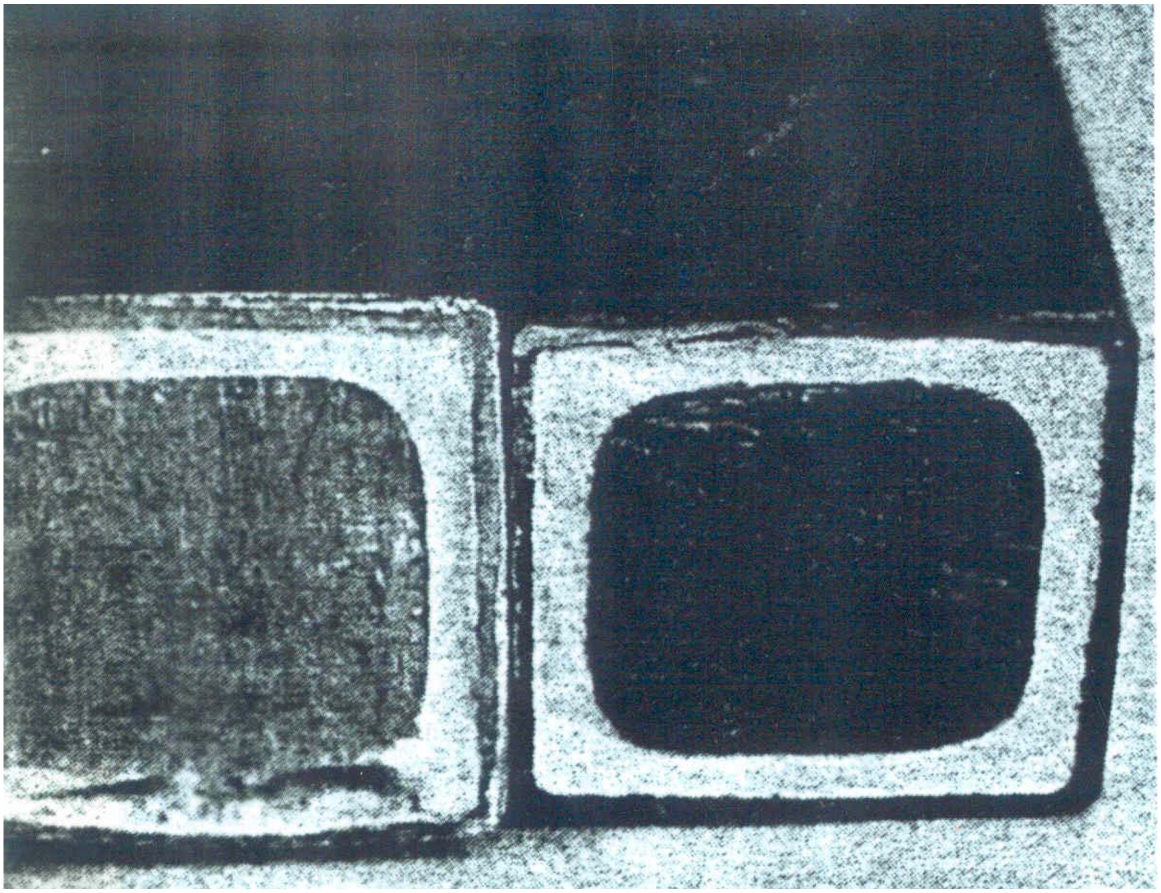
Wire is optimized for high field, unlike the Outokumpu wire. Short samples are the result of using the guaranteed Ic times the number of wires (351).

Engineering current density:

70 A/mm^2 at 4 T

Not optimized – Cu:sc=3:1

This one is solid, but imagine the inner solid piece has a hole in it that will be filled with superconducting wires.



This would be metal oxide (magnesium oxide) around a standard CICC. The outer sheath would be stainless steel and the coil welded for strength. Cable is under development by Pyrotenax (Tyco Controls of Canada).